Gear Test Assembly – Report of Experimental Testing – FY2020

Nuclear Science & Engineering Division

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prepared by
E. Kent, H. Belch, C. Grandy, D. Kultgen, M. Weathered
Nuclear Science and Engineering Division, Argonne National Laboratory

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Executive Summary

The Gear Test Assembly (GTA) has completed Campaign #2 of in-sodium testing at the Mechanisms Engineering Test Loop (METL). Campaign #1 was conducted in 2019 and completed 19,600 cycles, correlating to 9,800 fuel assembly maneuvers. Campaign #1 was terminated following a shaft seizure caused by a failed bearing in the sodium gearbox. Campaign #2 was conducted in the spring of 2020 and completed 2,768 cycles, correlating to 1,384 fuel assembly maneuvers. Campaign #2 was terminated following elevated vibration measurements coming from the sodium gearbox. Following cleaning and disassembly, a bearing was found to have failed in the sodium gearbox. Campaign #1 used tapered roller bearings made of 52100 steel with a heat treatment from the manufacturer that allows for operation to 350°C. Campaign #2 used the same tapered roller bearings, but with no heat treatment. A new dynamic shaft seal design was used in Campaign #2 that led to significant reductions in argon consumption and graphite debris generation. A modified external gearbox system led to no external bearing failures and allowed for higher torque output. Finally, modifications to the Carbonation System led to a more effective carbonation process and all-around reduction in turnaround time.

Introduction

Gear Test Assembly

The Gear Test Assembly (GTA) is an experimental apparatus designed to test mechanical components used in advanced fuel handling systems of liquid-sodium cooled fast-spectrum nuclear reactors (Figure 1). The need for advanced fuel handling system testing was identified during a component and infrastructure technology gap analysis for advanced reactors that was performed for the DOE-NE Advanced Reactor Concept (ARC) program in 2009. Reviews of existing documentation indicated a lack of testing for specific mechanical components used in the construction of advanced fuel handling systems. Most historical dynamic testing performed to-date uses a pin rubbing on a plate to test various materials for friction, wear, and self-welding. The existing data is insufficient for proper lifetime calculations of gearing components which operate under load in a high temperature flowing liquid sodium environment. The loads applied to the components in the GTA are based upon maximum design loading conditions calculated for a fuel handling system under conservative operating conditions. The GTA is the first test article designed for testing in the Mechanisms Engineering Test Facility (METL). Current information of the METL facility can be found in ANL-ART-210/ANL-METL-24 "Mechanisms Engineering Test Loop (METL) Operations and Testing Report – FY2020" [1].

The GTA system is designed for maximum testing flexibility and can accommodate various sizes of normal and parallel helical spur gears and mechanical roller bearings. The system can also be modified to test worm gears and straight or spiral bevel gears as well as other bearing geometries with minimal replacement of parts inside the liquid sodium testing environment. Figure 2 shows a cut-away of the test gearbox, and Figure 3 shows an exploded view of the system. Resulting data are taken using vibration probes, torque sensors, tachometers, thermocouples, etc. and compiled with data recorded by the METL system on sodium flow rates, purity, and temperatures. There is considerable reserve capacity in the system for additional measurements devices. There was extensive pre- and post-test non-destructive evaluation (NDE) analysis of the gears to determine the onset and evolution of mechanical failure.
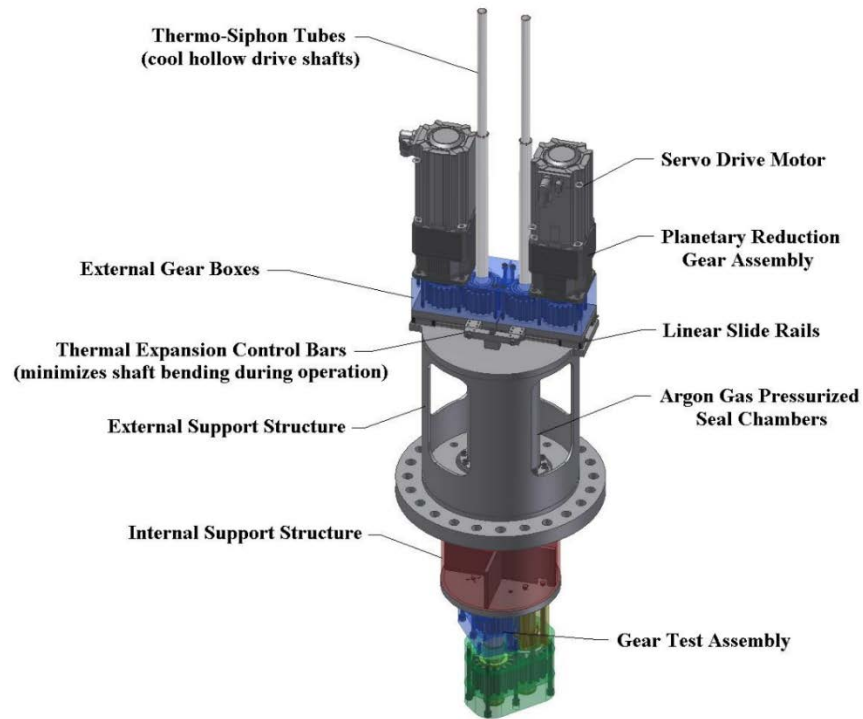
Figure 1: Overview of GTA System.
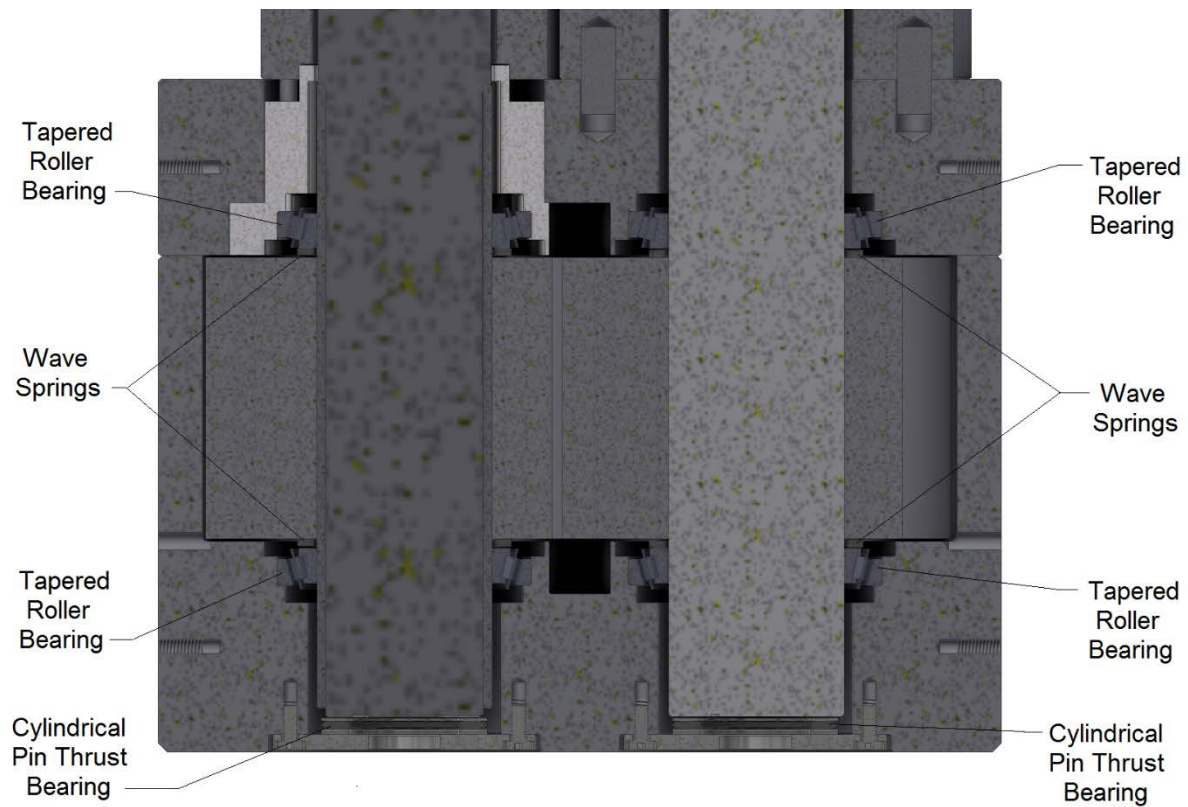
Figure 2: Cross-section view of the test gearbox.

Figure 3 - Exploded view of GTA - showing test gears and primary drive gears

The GTA was designed to accommodate spur gear sizes in the range of six-inch diameter and smaller. The design maximum torque applied to the input shaft is approximately 6,000 inch-pounds and is applied by a pair of Parker DC servo motors through a 7:1 Stober reducing gearhead. This type of peak force (with margin) may be required to release a stuck core assembly during refueling operations. The weight of a commercial size core assembly can be approximately 1,000 pounds. Continuous loads are applied during GTA operations simulating the entire removal process of the core assembly. The duty cycle for testing is shown in Table 1, the gears will be subjected to the following forces which simulate a potential maximum load with margin.

The loading procedure starts at step 1 at the maximum load expected for 2 seconds (to simulate core assembly being released from the grid plate structure and surrounding core assemblies).

While continuing to turn, the resisting load is reduced to simulate handling of the dead weight of a typical commercial-size fuel assembly in step 2 for 58 seconds. At the final step in removing the core assembly, the loading proceeds to step 3 where the motion pauses for 30 seconds (to simulate time during other motions of the fuel handling system) and the control system reverses the motor directions and motor operation modes from driving to resisting (and vice versa).

With the direction reversed, the simulated core assembly weight is lowered in step 5 for 58 seconds. The load is suddenly increased in step 5 to simulate contact of the core assembly nose piece into the inlet plenum for 2 seconds. The motion is paused again for 30 seconds (to simulate other motions of the fuel handling system) in step 6 while the control system reverses the motor directions and motor operation modes from resisting to driving (and vice versa). The test duty cycle then begins again at step 1 and continues until testing completes or interim inspections and measurements are required or component failure occurs.

Table 1: GTA Designed Torque Profile.

Load Step	Torque at Gear [in-lbs.]	Time [s]	Motor A Operation Mode	Motor B Operation Mode	Equivalent Process in Core Assembly Handling Procedure
1	6,000	2.0	Driving	Resisting	Lifting core assembly with resistance due to adjacent core assembly load pads and nose piece to grid plate removal
2	1,000	58.0	Driving	Resisting	Lifting core assembly weight
3	0	30.0	Dwell	Dwell	Core assembly vertical position unchanged during horizontal traverse (motor direction and operation reverses)
4	1,000	58.0	Resisting	Driving	Lowering core assembly weight
5	6,000	2.0	Resisting	Driving	Lowering core assembly with resistance due to adjacent core assembly load pads and nose piece to grid plate insertion
6	0	30.0	Dwell	Dwell	Core assembly vertical position unchanged during horizontal traverse (motor direction and operation reverses)

In October 2018, all necessary pre-sodium commissioning work was completed in Building 206 and the GTA was moved to Building 308. The GTA was assembled in the experimental test

assembly workstation on the METL Mezzanine to ready the system for insertion into Test Vessel 1 (Figure 4). All supporting electrical hardware and support instrumentation needed to be moved and installed in 308 to properly operate the GTA. This hardware included:

- 2x 480 VAC Transformers
- 480 VAC Disconnect Panel for Motor Power
- 240 VAC Disconnect Panel for Heater Power
- 2x Parker Compax3 Motor Controllers with Braking Resistors
- Argon Gas Supply Manifold
- Instrumentation and Control Panel including:
  - Parker ACR Programmable Motor Controller
  - Parker EPX2 HMI
  - NI cDAQ-9188XT
  - NI9428 Analog Output Card –SSR and Solenoid Valve Control
  - NI9208 4-20mA Input Card – Pressure Transducer and Torque Sensor Input
  - NI9213 Thermocouple Card – Temperature Input
  - NI9234 Voltage Input Card – Vibration Sensor Input
  - Watlow EZ-Zone RM Integrated Controllers
  - Watlow EZ-Zone Remote User Interface Modules.
  - Futek Torque Sensor Amplifier
  - 24VDC SSRs
  - Ethernet Switch

Figure 4: The GTA during qualification in Building 308.

Operational History – Campaign #1

Testing

The first experimental campaign began on February 5, 2019 with the GTA installed in Test Vessel 1. The GTA was then baked out at the operating temperature of 250°C for several days, the test vessel was filled with sodium to the overflow line, and the sodium was purified using the cold trap prior to operating the gears. Testing took place 24 hours a day for the majority of the campaign and lasted until the system seized, preventing shaft rotation, on March 7, 2019. A total of 19,600 testing cycles were completed, which is equivalent to 9,800 removal and insertion maneuvers for a core assembly.

Due to limitations imposed by the Parker brand motor controllers, the maximum torque value used in this first campaign was 4,500 in-lbs. The lower torque value of 1,000 in-lbs. was retained for the portion of the operation that mimics the dead weight of a core assembly.

Sodium Bearing Failure

After removing the GTA from Test Vessel 1 and cleaning the residual sodium, the GTA was disassembled. It was discovered that one of the sodium bearings had a failure, leading to the system seizing up. The sodium bearings used in this campaign were Timken brand tapered roller bearings fabricated out of 52100 bearing steel and heat treated to allow for operation up to 350°C. Post operation micro-hardness testing of the bearing components (Figure 5) revealed the cage material was not 52100 steel, but likely a lower grade carbon steel. Figure 6 and Figure 7 show the condition of the failed bearing during and after removal and cleaning. The physical condition of the bearings, along with the micro-hardness data, suggest the failure occurred at the cage.
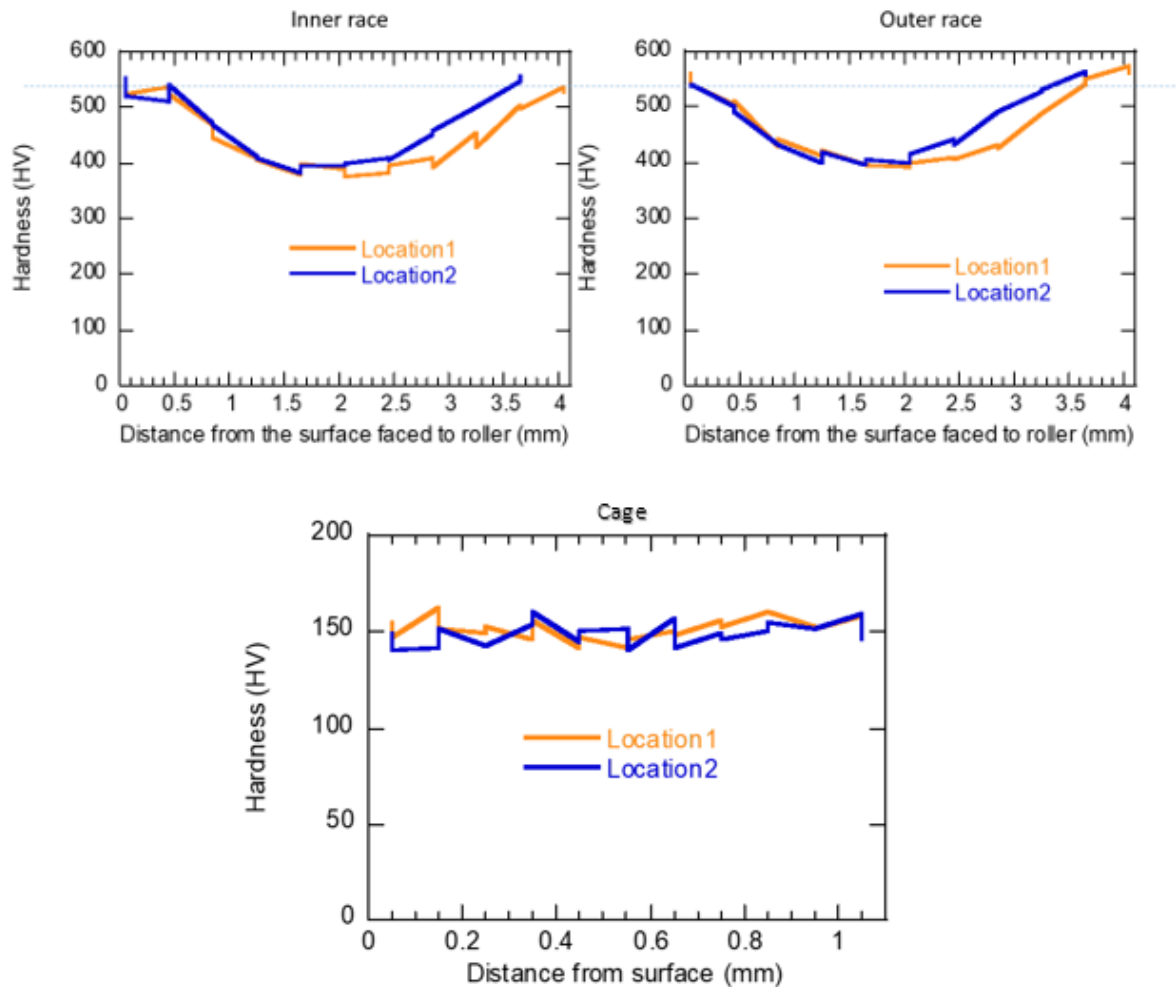
Figure 5: Micro-hardness testing of cross-sections of the inner race (left), outer race (right), and cage (bottom).

Figure 6: Condition of failed bearing found during disassembly. Note that the rust on the bearings was a result of the water bath used during disassembly.

Figure 7: Image of failed bearing cage (left), failed bearing inner race w/ rollers (center), and an untested bearing.

External Gearbox Bearing Failures

During the first campaign, there were several failures of the bearings in the external gearboxes that connect the drive motors to the drive shaft (Figure 8 & Figure 9). This gearbox was originally

designed as an open gearbox due to concerns of over packing the gearboxes with grease, potentially leading to a failure. This reduction in lubrication, along with the possibility that the gearboxes were excessively preloading the bearings, led to multiple external bearing failures. This required a temporary shutdown of the GTA, disassembly of the external gearboxes, and replacement of the failed bearings.

Figure 8: Image of failed external gearbox bearing showing wear and deformation caused by lack of lubrication and excessive bearing preload.

Figure 9: Image of damaged rollers taken from failed external gearbox bearing.

Residual Sodium Removal

The residual sodium removal method uses moist CO_2 to convert the sodium to sodium bicarbonate (baking soda). This is the preferred method for this work as the reaction is slow, doesn't generate significant heat, and the reaction product is benign. This process is performed in the Carbonation System that is installed on the east end of the METL facility. It consists of a heated water tank (bubbler) through which dry CO_2 is bubbled to pick up moisture. This bubbler, and the associated instrumentation, is located off the METL mezzanine to keep the water away from METL's sodium inventory. The moist CO_2 that exits the bubbler is introduced into a reaction chamber that is a twin of the 28" Test Vessels used on METL. The reaction chamber includes an adaptor flange to allow for installation of smaller 18" Test Vessel articles, like the GTA. Inside the reaction chamber, the moist CO_2 can slowly react with the residual sodium to clean the GTA while preventing any additional wear or damage to the components. Figure 10 shows a simplified P&ID for the

Carbonation System. Figure 11 and Figure 12 show the results of the process, where the white fluffy-looking material is the sodium bicarbonate.
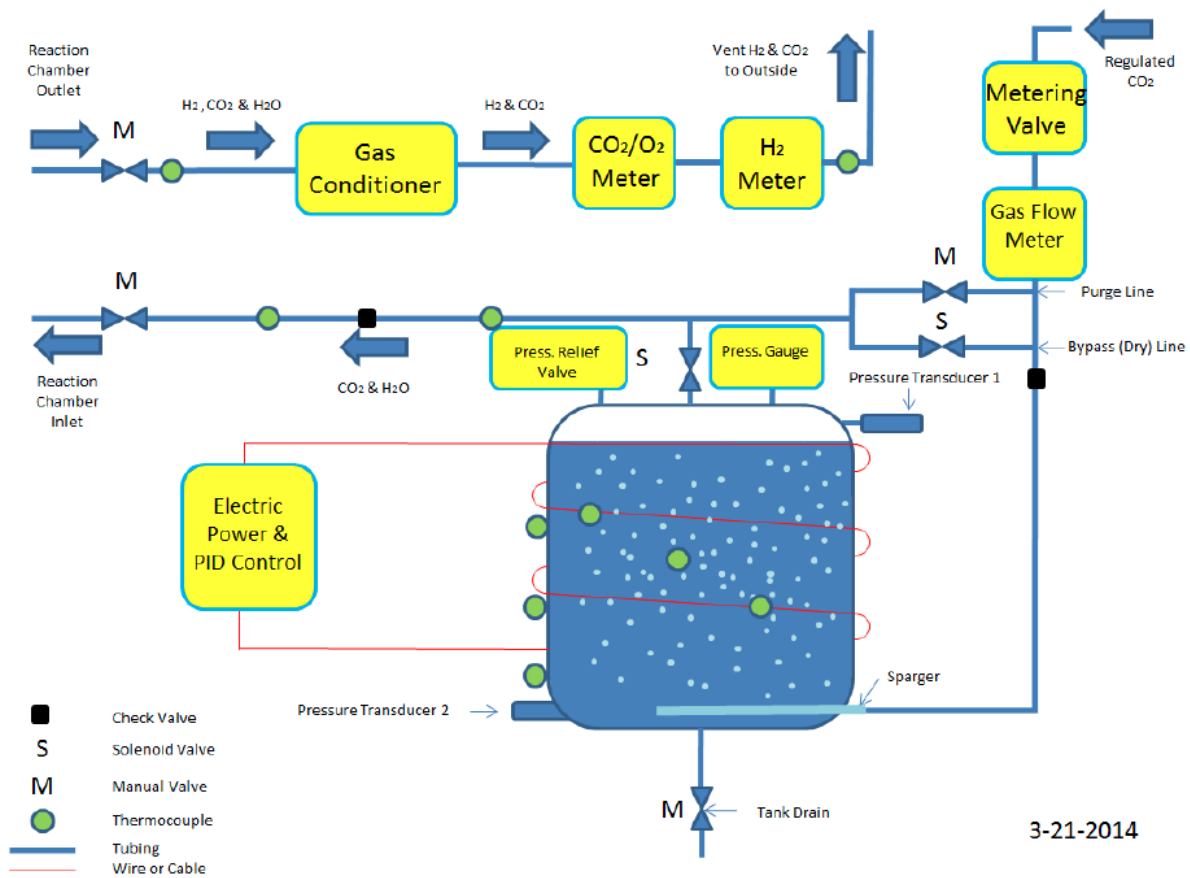
Figure 10: Simplified P&ID of the Carbonation System.
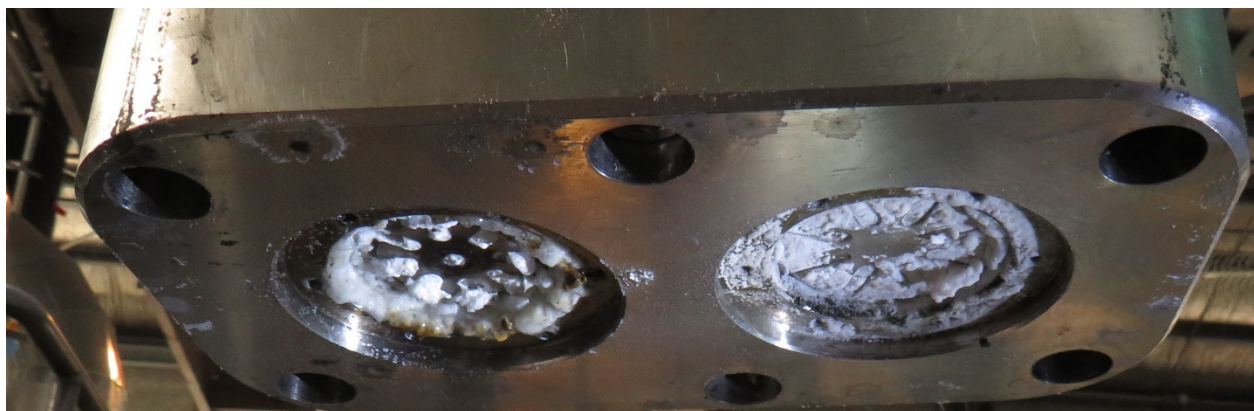
Figure 11: Image of lower sodium gearbox with bearing plates removed to show the production of sodium bicarbonate (white fluff).

Figure 12: Image inside the lower weldment showing the sodium bicarbonate product (white fluff) that has expanded and fallen off the GTA.

While the Carbonation System was able to react most of the residual sodium away, the process led to some difficulties during disassembly. As the sodium reacts to produce sodium bicarbonate, the product expands in volume roughly by a factor of five [2]. This was problematic in places where there wasn't room for the sodium bicarbonate to expand, most notably the thin clearance gap between the gears and the shaft (Figure 13). The expansion of sodium bicarbonate between the gears and shafts tightly bound the gears to their respective shaft.

To proceed, it was decided that the sodium bicarbonate needed to be dissolved into solution to effectively free the gears. An alcohol bath was used first to react away any pockets of sodium that may have remained hidden. Next, a water bath was used to dissolve the sodium bicarbonate. Both baths used an ultrasonic cleaner with heater (Figure 14) to more effectively clean the components. Following these baths, the gears were readily removed.

Figure 13: Image showing sodium bicarbonate "caked" between the gears and the shafts.

Figure 14: Ultrasonic bath setup used to free the gears from their shafts.

Design Changes

Dynamic Shaft Seal Redesign

The design of the GTA includes two drive shafts that penetrate the main flange. It is important to seal this feedthrough to ensure no oxygen (or other contaminants) enter the system, as well as to prevent any sodium vapor from exiting the system. The seal used during the first campaign (Figure 15) consisted of a seal chamber (#1), composite graphite seal rings (#9), custom Belleville washers (#6), and silicone O-ring seals (#10, 18, 19). The graphite rings sit in a machined pocket in the flange. The custom Belleville washers sit on top of the graphite and are compressed by the seal chamber as it is fastened to the flange. The graphite acts as the main seal, while the upper O-ring seal allows the operator to pressurize the volume inside the chamber. By setting the pressure inside the chamber to a value higher than the pressure inside the test vessel, a preferential leak path is established from the seal chamber into the test vessel. This ensures that no sodium vapor can escape past the seal.
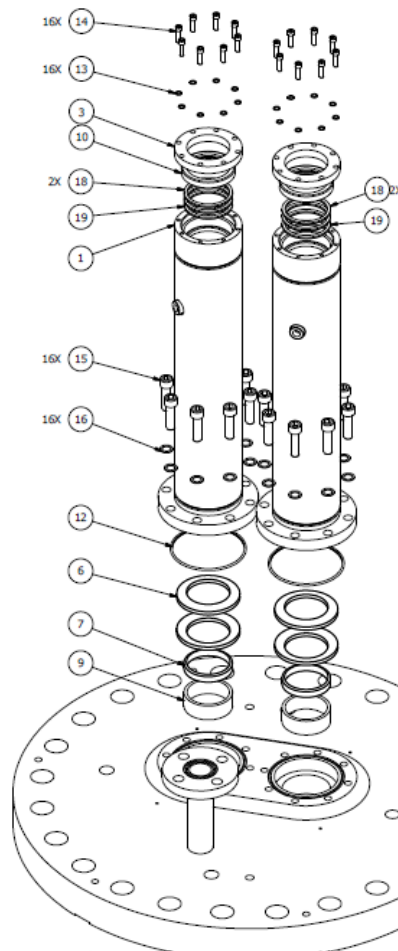
Figure 15: Original dynamic shaft seal design.

A few days into the first campaign, the seal chambers would no longer hold a pressure higher than the test vessel. This indicated that the graphite ring had failed. Operation continued as the O-ring seals on the top of the chamber held and this allowed for continuous flow of argon from the seal

chamber into the test vessel. While this consumed a considerable amount of argon, the seals held throughout the first campaign.

The seal system included a graphite catch below the flange inside the gas space of the GTA. During disassembly, a significant amount of graphite was found in the catches. The catches were designed to hold >7x the volume of the graphite rings, but fragmentation of the seal led to an increase in volume. As seen in Figure 16, the graphite reached the top of the lip and likely had some spill over into the test vessel. While a small addition of carbon to the sodium inventory is not a major concern, this issue needed to be addressed.

Figure 16: Graphite flakes filling graphite catch.

An additional issue with the original seal design was the required use of silicone O-ring lube for the top seals. This lube eventually made its way past the O-ring seals and travelled down the shaft. While silicone is compatible with sodium, this is a potential contamination route. Figure 17 shows the condition of the shafts during disassembly. Silicone lube is visible on the shaft, particularly where residual graphite has stuck to the lube.
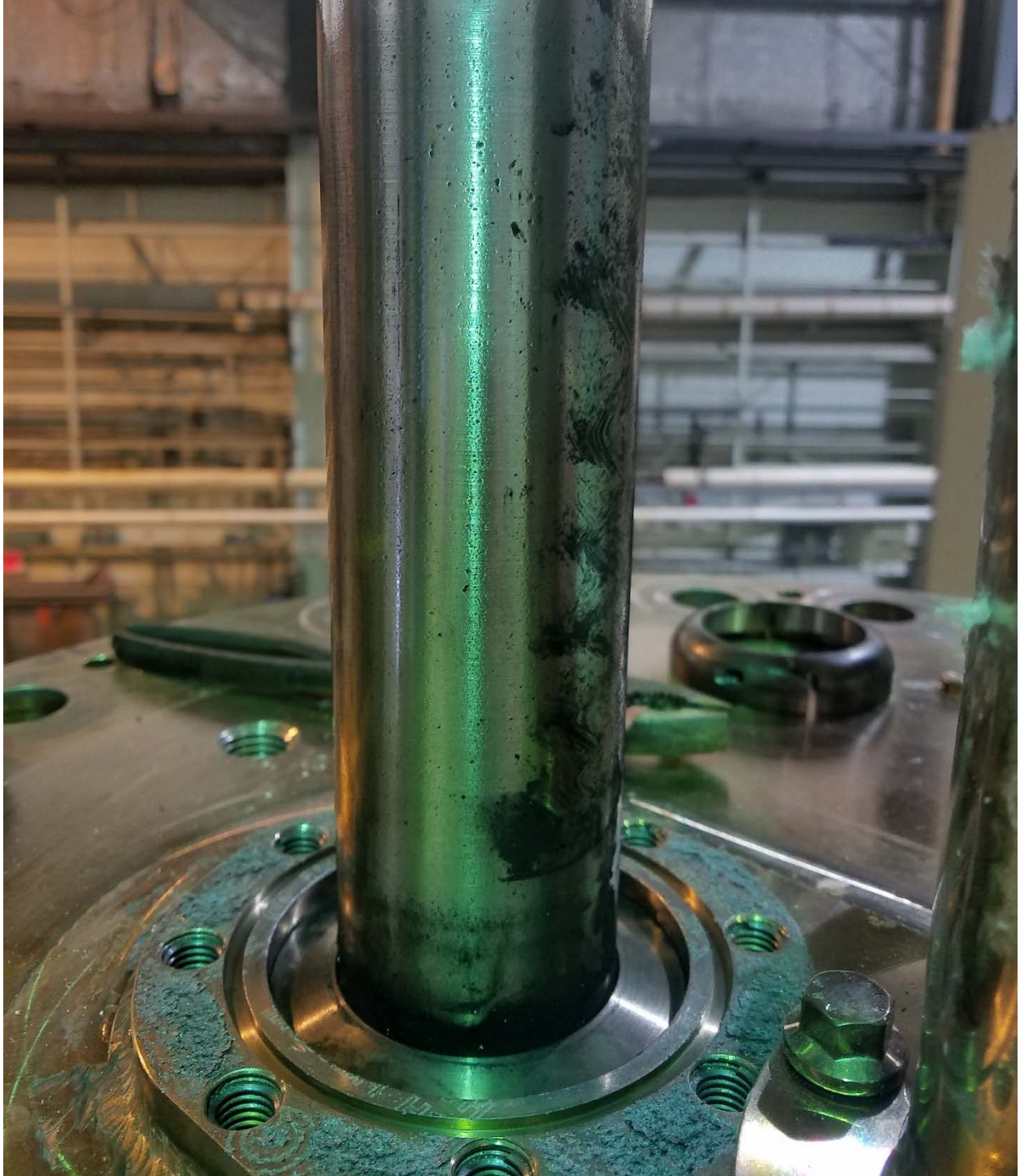
Figure 17: Image of the drive shaft during disassembly. Note the coating of clear silicone lube on the shaft, as well as graphite residue that has stuck to the lube.

While the original seal system performed sufficiently during the first campaign, a number of design changes were desired. The composite graphite rings were too fragile for this operation, and an excessive amount of silicone O-ring lubrication was used. A new dynamic shaft seal was designed to accommodate these desired performance enhancements. The new design, shown in Figure 18,

consists of a body that seals to the GTA flange (#1), lower and upper braided graphite cord seals (#2), a lantern ring (#3), and a follower that is used to compress the assembly (#4). The lantern ring provides a small volume inside the seal that can be pressurized with argon, similar to the seal chamber on the previous design. Two graphite cords are used below the lantern ring and three graphite cords are used above the lantern ring. This configuration establishes a preferential leak path going from the lantern ring into the vessel, instead of from the lantern ring up past the follower and out to the environment. The use of flexible graphite cord and the seal follower allowed for re-torqueing of the seal when an increase in gas flow is observed. All seal body materials are 316SS.
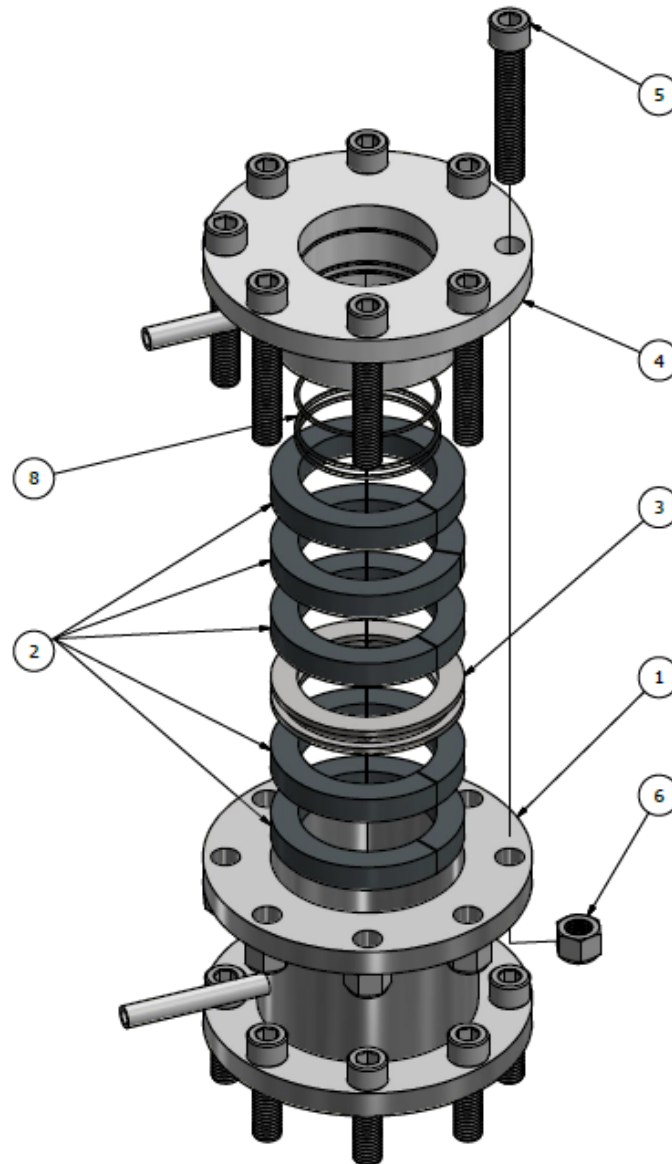
Figure 18: Lantern Ring Seal.

Inspection of the graphite catch during the second campaign disassembly process found a significant reduction in graphite debris. While the second campaign only operated roughly 10%

the duration of the second campaign, the reduction in graphite debris suggest the new shaft seal design performs more effectively.

Figure 19: Significant reduction in graphite debris using new seals.

External Gearbox Modifications

The bearings in the external gearbox that mate the motors to the drive shafts failed multiple times during Campaign #1. The lack of lubrication and excessive preload of the bearings likely lead to their early failure. To address the lack of lubrication, a seal plate and grease port were added to the external gearbox assembly. The seal plate helped to close the bottom of the gearbox, preventing grease from escaping the system. The grease port allowed for additional grease to be added to the gearbox as the system operated. Figure 20 shows the external gearbox with the modifications, and Figure 21 is a cutaway of the gearbox to show how the seal plate helps to close the bottom of the gearbox. Additionally, shims were added during assembly to prevent excessive bearing preload. These modifications were implemented during the final stages of Campaign #1, and we're kept for Campaign #2. No additional external bearings failures have been experienced.
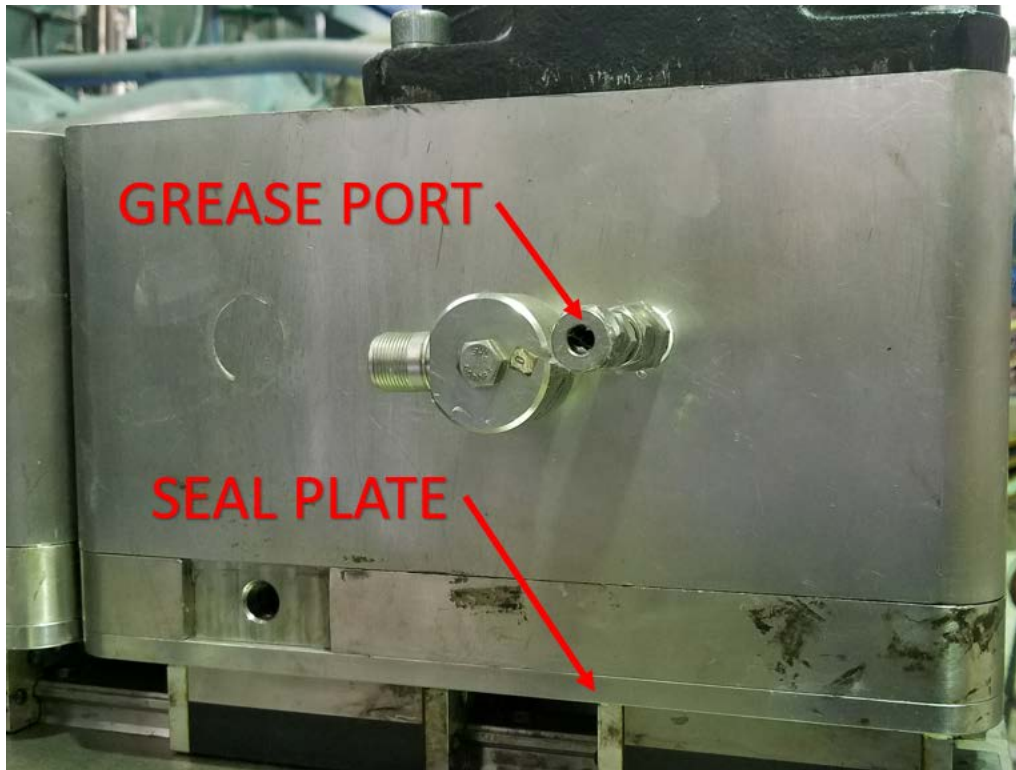
Figure 20: External gearbox with added grease port and seal plate.
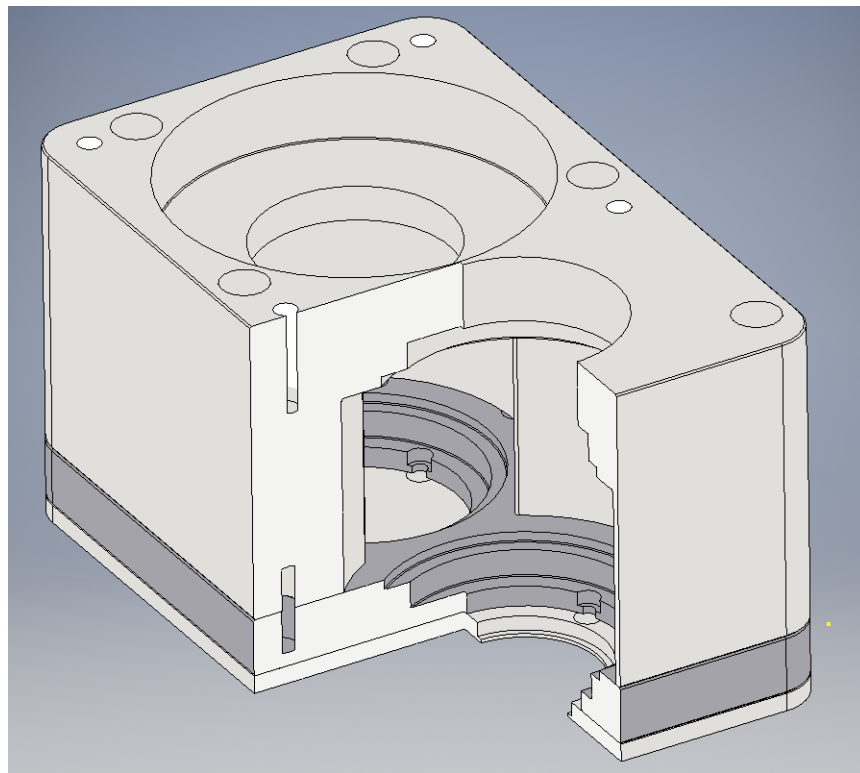
Figure 21: Cut-away of the external gearbox to show the effect of the seal plate.

Another modification to the external gearbox assembly addressed the max torque limitations experienced during the first campaign. A Parker brand 15:1 planetary gearbox replaced the Stober brand 7:1 planetary gearbox. This allowed for higher torques at the cost of max RPM. Campaign #2 operated at the same torque values as Campaign #1, but will be increased in the future.

Torque Sensor Removal

An inline Futek brand torque sensor was used during pre-sodium work and Campaign #1 to confirm the torque values outputted by the motor controller. The error associated with the torque values coming from the motor controller were roughly 10% of the measurement, and there was a desire to obtain more accurate data. Unfortunately, the Futek torque sensor confirmed that the "error" associated with the measured torque value is not a measurement uncertainty, but a symptom of the DC servomotor's operation. Figure 22 shows a comparison of torque measurements made by the motor controller and the Futek sensor. The inclusion of the Futek sensor complicated the assembly and operation of the external gearbox assembly, so this was removed for Campaign #2 as it contributed little useful data.
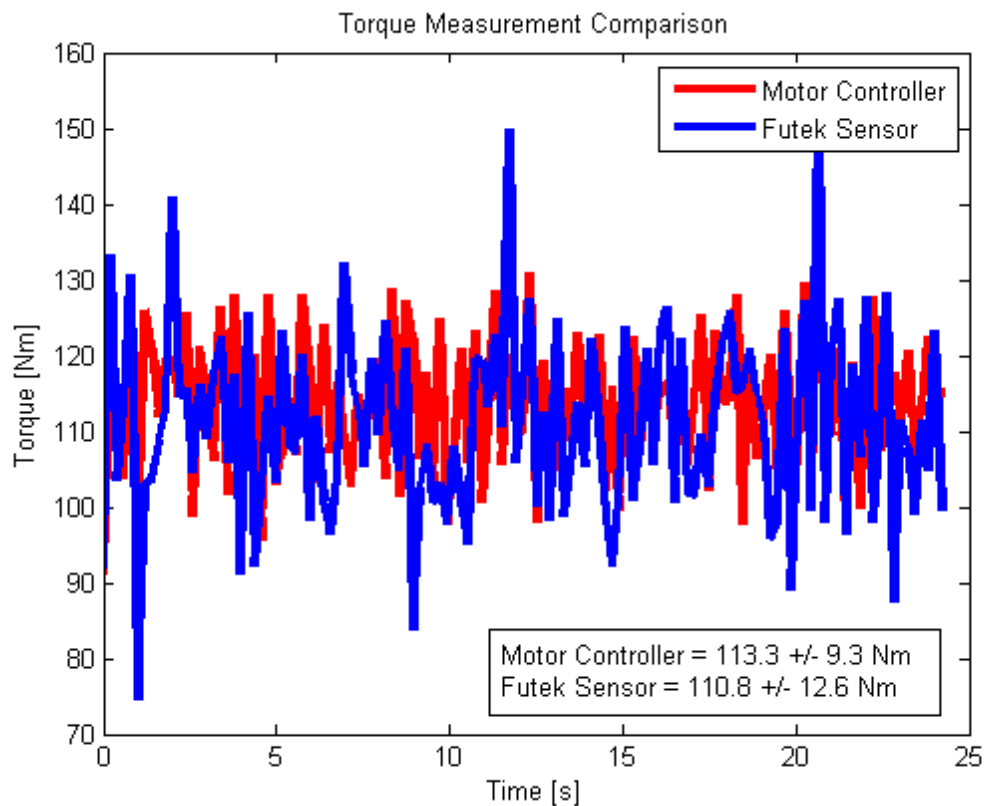

Figure 22: Torque measurement comparison.

Experimental Campaign #2

Testing Overview

In early 2020, the design changes to the GTA were completed and the system was reassembled in building 308. This assembly used the same Timken tapered roller bearings made of 52100 bearing steel, but this set was not given the same heat treatment as the first set. Efforts to design and fabricate a custom roller bearing system were being performed alongside the GTA work, but a finished set was not available at assembly. The untreated Timken bearings are readily available with minimal lead time, where the heat treated bearings have a 3 to 4-month lead time and roughly 18x increase in cost. The decision to use the inexpensive off-the-shelf variant allowed operation to begin immediately. Though the system now had gearboxes capable of applying the intended max torque of 6,000 inch-pounds, the max torque of 4,500 inch-pounds was retained to better compare the bearing performances. Following a re-commissioning of the system, the GTA was installed in Test Vessel 1 on February 25, 2020. The GTA and Test Vessel 1 were then baked-out at 250°C to remove any residual moisture. On March 3, 2020 Test Vessel 1 was filled to the overflow line with sodium and the sodium purification process was started.

Campaign #2 of experimental operations began on March 18, 2020. Testing was performed during normal work hours until March 20, 2020 when Argonne National Laboratory went to "min-safe operations" due to the COVID19 pandemic. The GTA was put in a safe state in Test Vessel 1, which remained filled with sodium at 250°C. The system was left in this configuration until May 25, 2020 when the METL team was allowed to return to campus to continue experimental operations. The system experienced a 69-day sodium soak at operating temperature, and the effects of this on the various components are unknown. A thorough checkup of the system was performed to determine if any of the components were experiencing issues, but the system performed as expected. Testing was resumed March 28, 2020 after the system was deemed safe to operate.

GTA testing proceeded during normal work hours until June 15, 2020, when the sodium gearbox vibration sensor detected a significant rise in vibration. The shafts were still able to rotate, but the indication from the vibration sensor justified a system shutdown. Campaign #2 completed 2,768 cycles which is equivalent to 1,384 fuel assembly removal-insertion maneuvers. This was roughly 14.1% the testing duration of Campaign #1.

Vibration Analysis

Higher fidelity vibration data was collected during Campaign #2, and some is presented below. Figure 23 shows a 1-second capture of the raw accelerometer data, with absolute max and standard deviation values indicated. The max and standard deviation values are used during normal operation to watch for elevated gearbox vibration. Data is collected during healthy runs to determine baseline vibration values. A condition is then set in the LabVIEW control program such that the system will shut itself off and notify the operator if vibration values exceeding 2x the baseline are detected. This is the control feature that detected the fault in Campaign #2.
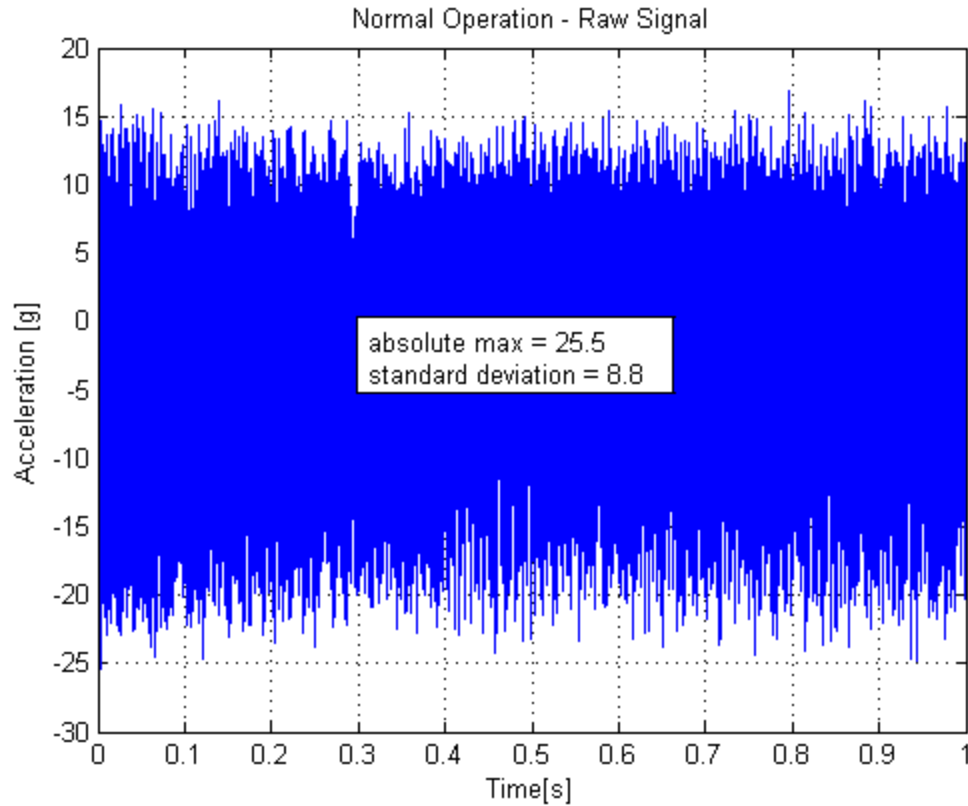
Figure 23: Vibration data taken at the sodium gearbox during normal operation.

Using Matlab, the data is transformed to the frequency domain using the Fast Fourier Transform algorithm to observe any periodically repeating accelerations. This is particularly useful in identifying gear failures, such as a broken or chipped tooth. Figure 24 shows the frequency domain vibration data taken during normal operations.
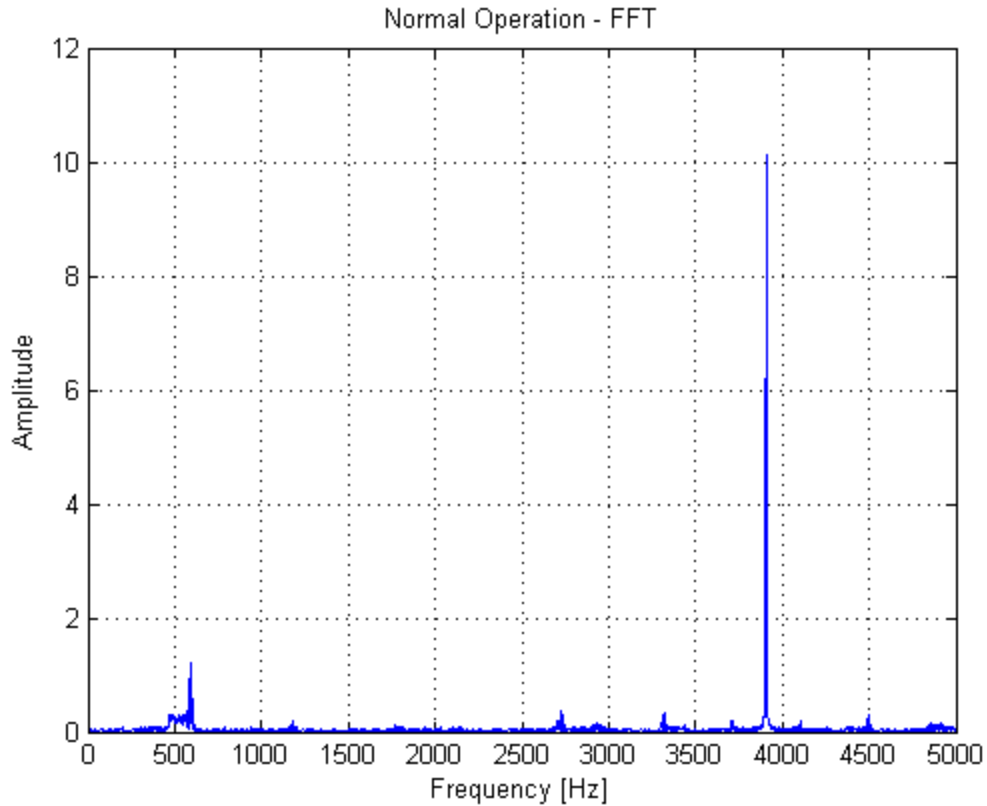
Figure 24: Frequency domain vibration data - normal operation.

The range of the presented data (0-5000Hz) is the maximum available due to the data collection limit of the vibration sensor. A significant peak is found near 3900 Hz, and no physical phenomenon related to the gearing points to this value. The rotational frequency of the shaft is 4.17 Hz (250 RPM), and the gear mesh frequencies are 91.7 Hz for the small gears and 62.5 Hz for the large gears. This peak is likely due to the operation of the DC servomotors. Vibration data taken with the servomotors on, but the shafts not rotating are presented in Figure 25 and Figure 26. The peak near 3900 Hz is again observed, suggesting this is not related to the mechanical operation of the GTA.
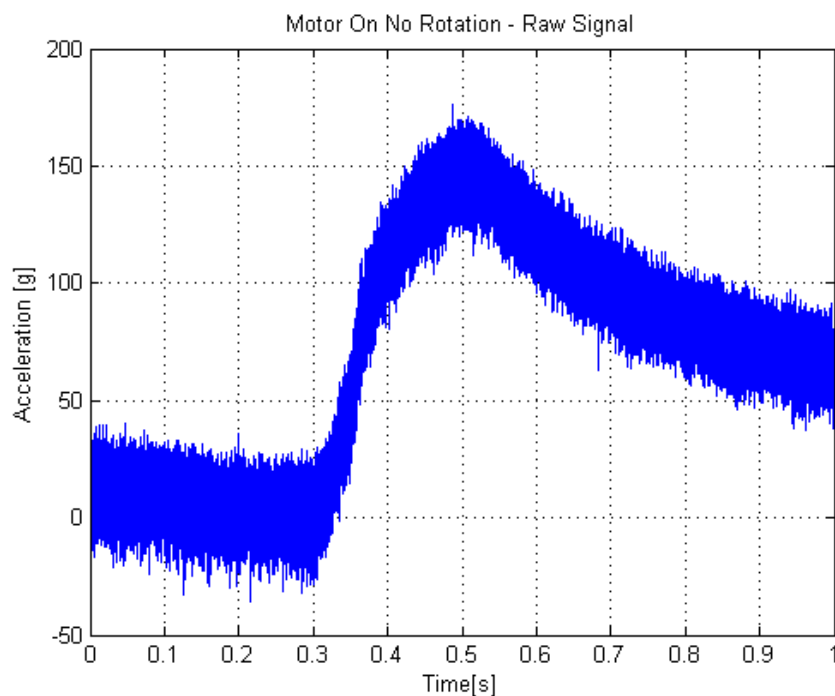
Figure 25: Vibration data taken at the sodium gearbox with the motors on, but no shaft rotation.
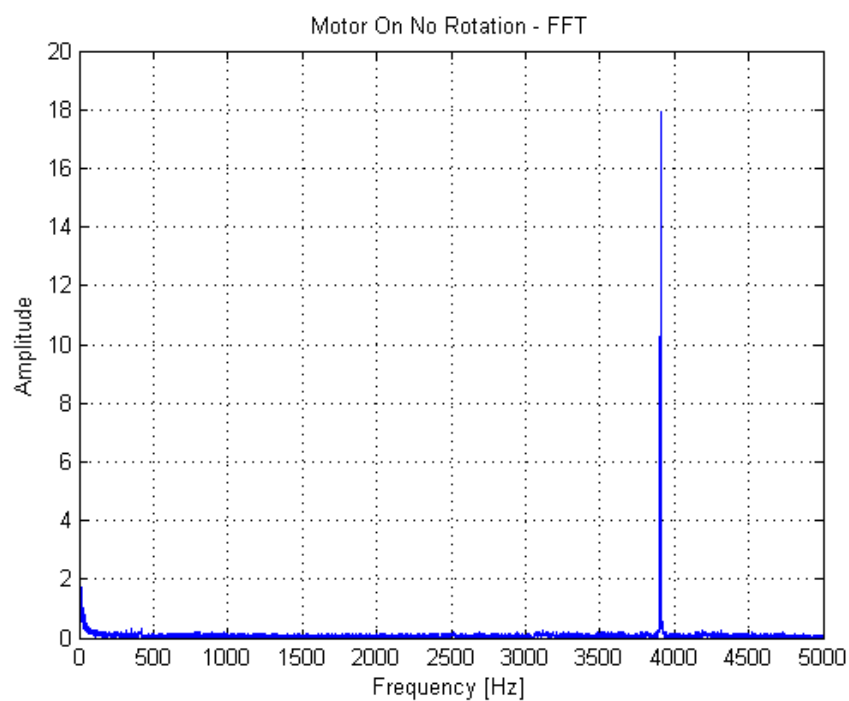
Figure 26: Frequency domain vibration data taken with the motors on, but no shaft rotation. The peak at ~3900 Hz seen in the rest of the data likely from servomotor system.

Figure 27 and Figure 28 compare vibration data collected at various periods of the second campaign. Baseline data from the beginning of the campaign is compared to data taken before and

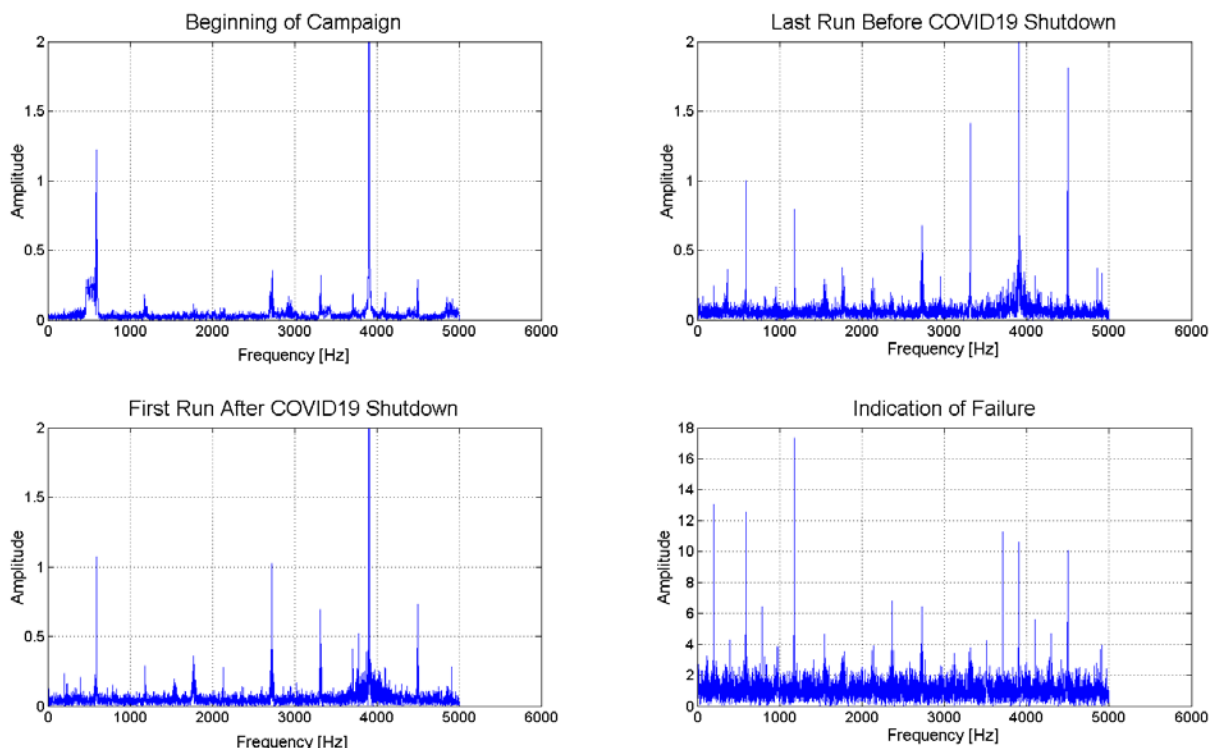after the 69-day soak at temperature. The data collected that lead to the fault indication is also presented.
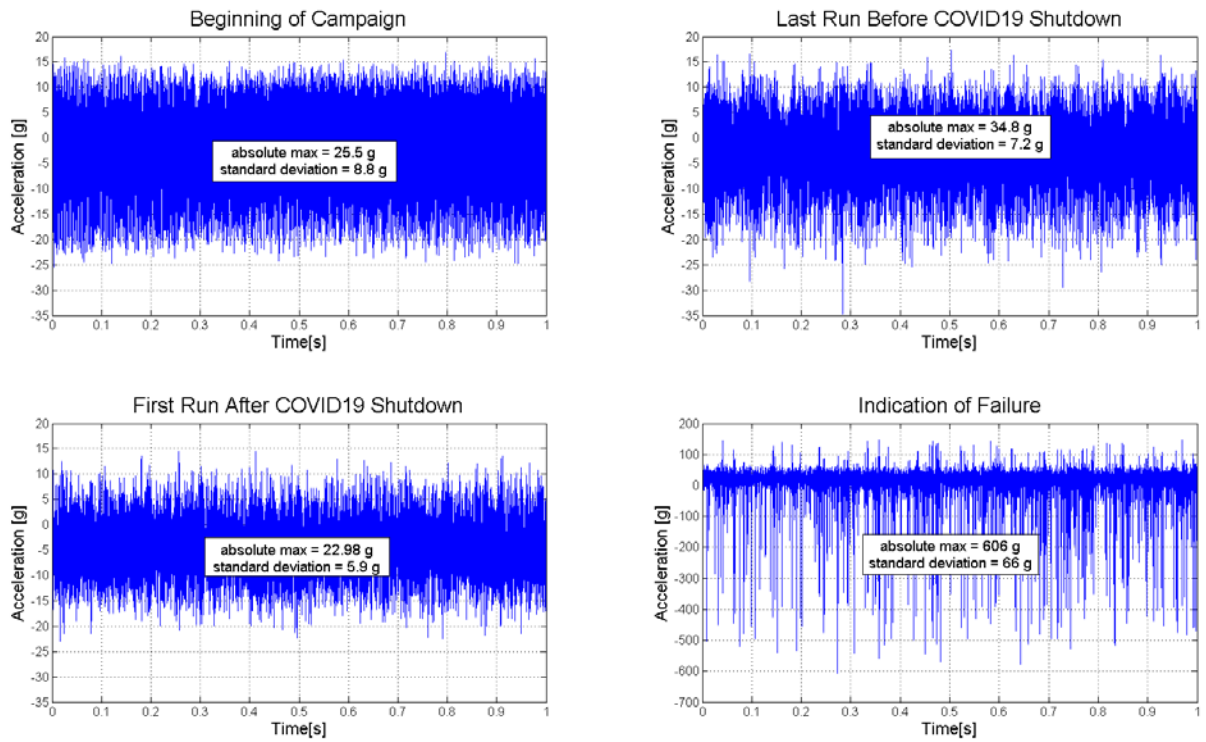
Figure 27: Raw vibration data taken at various stages of the second campaign.

Figure 28: Frequency domain vibration data taken at various staged of the second campaign.

No significant effects of the 69-day soak at temperature have yet to be identified. An obvious increase in vibration/noise is observed when comparing the fault indication data to the rest of the data presented. The max/standard deviation method of fault detection will remain in use, and development of a frequency domain fault analysis method will be pursued.

Cleaning and Disassembly

Modifications to the Carbonation System were made following the lessons learned during Campaign #1. A new control and monitoring LabVIEW program was developed to operate the system in a more efficient and autonomous manner. This new program included automatic fault monitoring to put the system in a safe state should the temperature, pressure, water level, or hydrogen generation exceed safe operating ranges. Band heaters were added to the reaction vessel (Figure 29) to prevent moisture from condensing on the vessel walls. This heating helps the carbonation process, as the moisture remains in the CO_2 gas and is then available to react the residual sodium. If the vessel walls are colder than the temperature of the bubbler tank, the moisture quickly condenses out and drains to the bottom of the vessel.
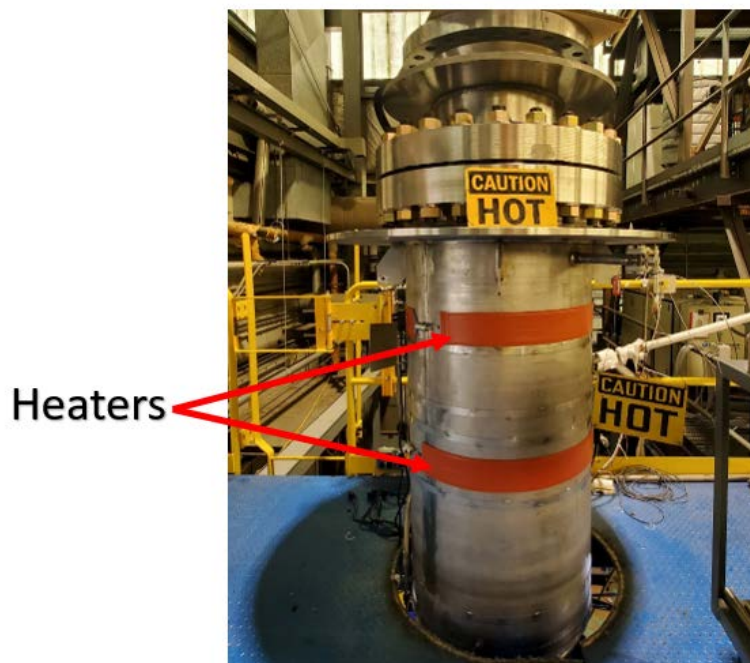
Figure 29: Heaters added to reaction vessel to prevent condensation.

The sodium gearboxes were designed with 0.250" holes to allow for sodium to drain out, but a considerable amount of unreacted sodium remained in the gearboxes following carbonation in Campaign #1. This was likely due to the holes plugging with sodium bicarbonate during the carbonation process, not due to sodium flow issues during the vessel drain. These holes were increased to a 0.500" diameter for Campaign #2 to allow for better drainage and carbonation penetration. The addition of reaction vessel heaters and bigger drain holes led to a more effective carbonation process. Figure 30 compares the reaction products that remained in the larger of the sodium gearboxes following the carbonation process. Campaign #1 had considerable amounts of unreacted sodium left in the gearboxes, most noticeably where the bearings were located (Figure 31). The modifications made for Campaign #2 greatly improved the extent of the carbonation. This is demonstrated by observing more white and flaky debris in the right image of Figure 30 and Figure 31.

Figure 30: Remaining reaction products following carbonation from campaign 1 (left) and campaign 2 (right). Drain holes added to gearbox, plus modifications to carbonation system significantly improve carbonation penetration.

Figure 31: Comparison of remaining sodium on bearings following carbonation process.

To further establish that the modifications led to better carbonation of the sodium, a timeline of both campaigns is presented in Table 2.

Table 2: GTA Experimental Campaign Timelines.

| Activity	Campaign 1	Campaign 2
Sodium Fill	2/1/2019	3/3/2020
Testing Start	2/5/2019	3/18/2020
Standby	-	3/20/2020
Restart	-	5/28/2020
Fault	3/7/2019	6/15/2020
Removal	8/6/2019	8/7/2020
Carbonation Start	8/6/2019	8/10/2020
Carbonation End	9/17/2019	8/18/2020
Cleaned & Disassembled	11/7/2019	9/2/2020

Carbonation was performed 24/7 for 42 days during the first campaign, minus the small sections of time the GTA was removed for inspection. Carbonation was performed 24/7 for 8 days during the second campaign. When comparing the results of the carbonation in Figure 30 and Figure 31, it is clear the second campaign had more effective carbonation with less operation time. The modifications to the carbonation process will be retained for future efforts.

Bearing Failure

Following the cleaning process, the GTA was fully disassembled to determine the source of the vibration. A bearing was found to have failed on the short drive shaft, below the small test gear. Figure 32 indicated the location of the failed bearing on the GTA. The bearing failed completely

with the cage, races, and rollers fragmenting into small pieces of debris. Figure 33 shows what remains of the bearing was found in the gearbox and in the fine catch screen. The catch screen was found to be in good condition, suggesting no bearing debris made it into METL.
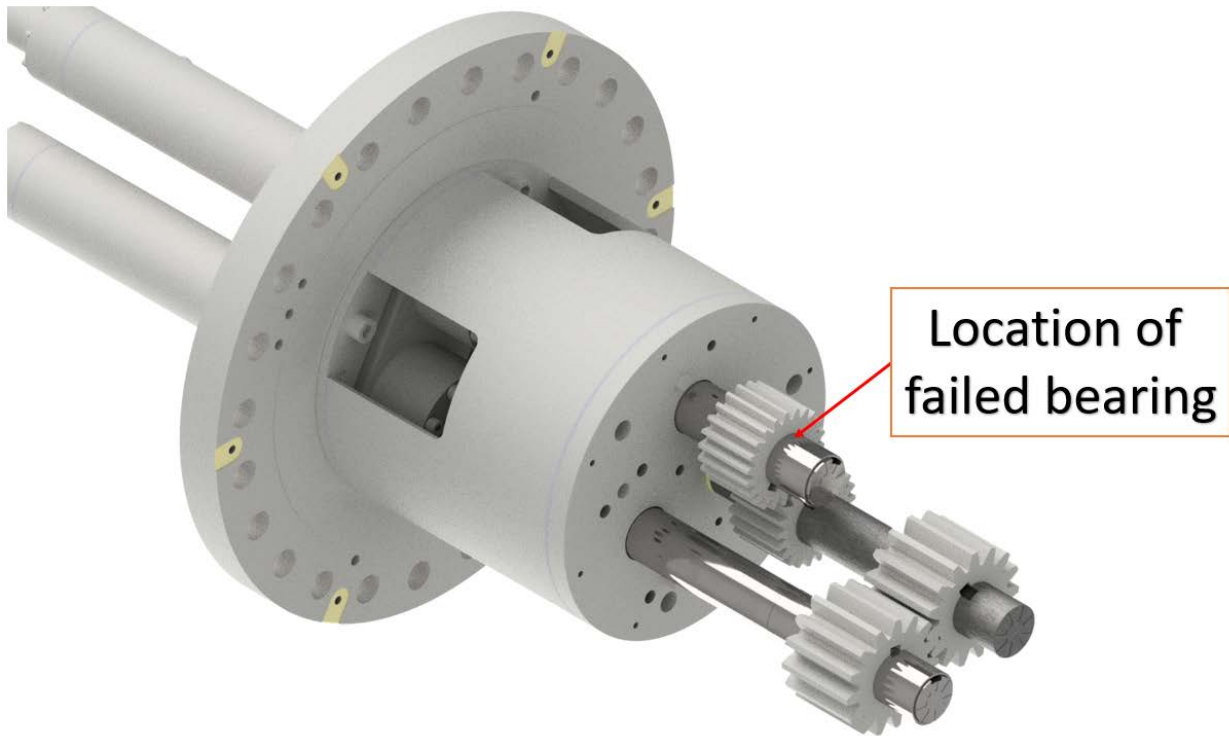
Figure 32: Partially disassembled view of GTA with location of failed bearing called out.

Figure 33: Remains of complete bearing failure.

The remains of the bearing failure damaged the shaft sleeve where the gears and bearings are mounted. Various attempts to remove the shaft sleeve while keeping it in a usable condition were unsuccessful, so the shaft sleeve was cut to allow for removal. Figure 34 shows the condition of the shaft sleeve following cutting. The orange and brown discoloration at the bottom of the sleeve indicate the area damaged by the failed bearing. New shaft sleeves are being manufactured to replace the damaged one. Once the new shaft sleeves are fabricated, the GTA will be reassembled for continued testing in the METL facility in FY21.

Figure 34: Shaft sleeve that required cutting for removal. Discoloration at end of sleeve caused by failed bearing.

Gear Wear

A suite of NDE methods are used to monitor the gear health over the course of testing. Pin-over measurements are made to monitor the gross wear of the gear teeth. Eddy current testing is used to examine the surface of each gear tooth. Finally, ultrasonic testing is performed to inspect the gear teeth and roots for crack formation. The gears were examined prior to sodium testing, following Campaign #1, and the post-Campaign #2 inspection is currently underway. No significant degradation of the gears is observable to the naked eye, but the NDE suite will verify this in the near future.

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Nuclear Science & Engineering Division

Argonne National Laboratory
9700 South Cass Avenue, Bldg. 308
Argonne, IL 60439

www.anl.gov